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A cryogenic treatment system for treating large rolls

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Abstract

Cryogenic treatment is a supplementary process of traditional heat treatment which has been acknowledged for many decades as an effective method for increasing wear life, dimensional stability and mechanical properties such as yield strength, hardness etc. A cryogenic treatment system for treating large rolls has been designed, built and tested. Liquid nitrogen has been employed to provide cooling capacities; and the temperature can be controlled from -180 ℃ to the room temperature with an accuracy of ±3 ℃ by the developed temperature controller. A 9Cr3Mo roll with the size of Φ260 mm has been cryogenic treated in this developed system. The test results show that most of the residual austenite would be changed into martensite after cryogenic treatment, which contributes to an improvement in hardness and dimensional stability.

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Keywords: Cryogenic treatment; furnace temperature uniformity surveys(TUS)

1. Introduction

With the development of metallurgical industry, the varieties of high-speed high-pressure roll mills have increasingly quality requirements for rolls, such as hardness, hardness uniformity, accuracy, stability and hardened layer depth and so on. Cryogenic treatment is generally considered to be an effective way for improving the quality of roll.

Cryogenic treatment refers to improve the microstructure and mechanical properties of materials by keeping the work piece in a controlled low-temperature environment; Zhang Hong et al. (2008). The traditional cooling

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approaches for cryogenic treatment mainly include carbon dioxide cooling (the available lowest temperature is -70℃) and liquid nitrogen mixed with n-propanol cooling (the available lowest temperature is -90 ℃). The technology of cryogenic treatment has been applied more and more extensively in the modern industrial with the development of the cryogenic technology; Zhang Hong et al. (2008). A customized cryogenic treatment system for treating large rolls which is cooled by the gasification of liquid nitrogen has been designed, built and tested. At present, a lower treating temperature can be achieved by this cooling method, which contributes to a higher quality of the rolls.

The temperature control for traditional cryogenic treatment is realized by adjusting the mixing ratio of the two cooling mediums, which is not very convenient somehow. As to the developed cryogenic treatment system reported here, the amount of liquid nitrogen injected to the chamber is controlled intelligently by a computer, which not only has a high precision, but also has a good adjustable temperature rate, tracking control and automatic process control functions and so on. The temperature distribution and flow field of the chamber has been much more reasonable after a careful optimized design of the deflector and the mixing system for cold nitrogen, which contribute to a more uniform temperature distribution and a reduced strain caused by stress; Guo Jia et al. (2011).

2. Design of the cryogenic treatment system

2.1. The introduction of the cryogenic treatment system

Fig. 1 shows the photo of the developed roll cryogenic treatment system, it includes two deep-cryogenic furnaces, control system, hydraulic system and transmission system of liquid nitrogen. This system is cooled by liquid nitrogen; and the advanced technologies of temperature control and liquid nitrogen dispersion have been employed; liquid nitrogen vaporizes first, and then the cold nitrogen is exchange heat with rolls under the action of rotation fan. Thus the latent heat and sensible heat could be fully used. In order to reduce the wastage of liquid nitrogen, a high vacuum transport tube has been employed.

Fig.1 Roll cryogenic treatment system

The two deep-cryogenic furnaces can be pre-cooled by each other and they can also work independently. The temperature of this system can be controlled from -180 ℃ to the room temperature with a temperature control accuracy of ±1 ℃. The temperature uniformity of the chamber is ±3 ℃ and the cooling rate is ⩽ 5 ℃ / min. The maximum size of the rolls that can be treated in this system is Φ500 × 4300 mm and the maximum load capacity is 6000 kg.

2.2. System simulation and test

Temperature uniformity refers to the differences between the actual measured temperature and the set point temperature within the treating chamber; Guo Jia et al. (2007). The temperature uniformity is very important for the rolls, as they will be deformed or even cracked because of the stress caused by the uneven temperature distribution. Therefore, in the development process of the system, a simulation and optimization of the structure of the deflector and the mixing system for cold nitrogen was conducted to determine the optimum exhaust fan parameters; and then a no-load test of the temperature uniformity has been conducted to verify the design.

The system model is established based on the actual needs and some similar equipment we have developed before, shown in Fig. 2. The boundary conditions set as follows: the power of fan is 15 kW, the flow rate is 7200 m3/h, and the pressure is 1100 Pa. In order to make the model more practical, a roll with the sizes of Φ450 ×3000mm was added into the model; the total weight of this roll is about 3000 kg.

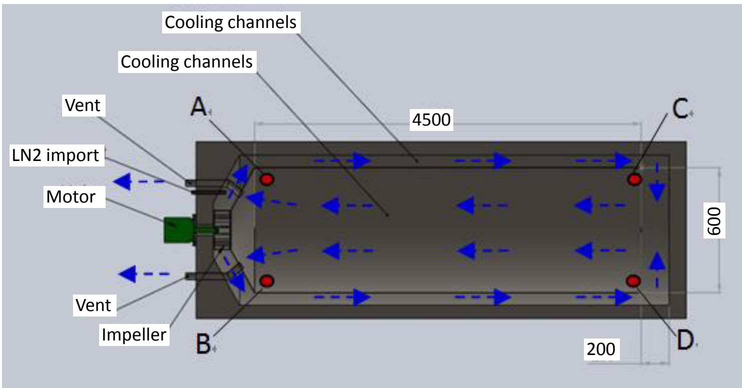

Fig.2 Roll cryogenic treatment system model

The simulation results which are simulated by FLUENT software are shown in Fig. 3 and Fig. 4. As can be seen from Fig. 3, the temperature difference among the position of A, B, C and D is between 193 K and 201 K. As the position of C and D are near the entrance of cold nitrogen while the position of A and B are near the exit, therefore, no wonder that the temperature of C and D are higher than A and B after a heat transfer between the cold nitrogen and the roll. The simulation of pressure field is shown in Fig. 4. The pressure of A and B is lower than C and D, besides, the temperature of A and B is much higher than that of C and D, therefore, the most suitable positions for exhaust vent are A and B.

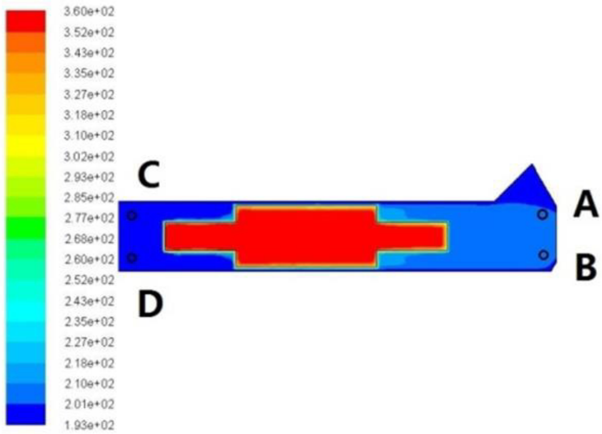

Fig.3 Temperature field simulation (contours in K)

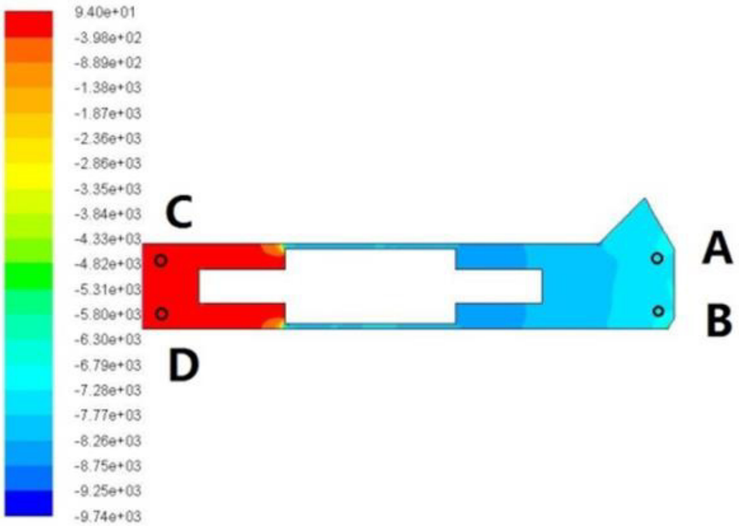

Fig.4 Pressure field simulation (contours in Pa)

A no-load test has been conducted referring to "GB / T 9452-2012", the install position of the nine PT-100 type temperature sensors which calibrated by the Cryogenic Metering Station of the Chinese Academy of Sciences with an accuracy of 0.1 K shown in Fig 5; the install positions 5-8 are near the entrance of the cold nitrogen and the install positions 1-4 are near the exit. The values of the nine temperature sensors were recorded after reaching its balanced state for 30 min at the temperature of -80 ℃. The sample period of each temperature sensor is one data per minute and the test and recording were lasted for 30 min; the temperature curve is shown in Fig. 6.

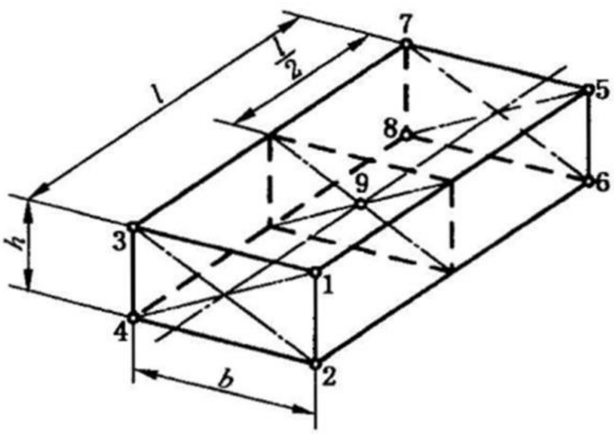

Fig.5 No-load test point arrangement (b=h=600 mm, I=4500 mm)

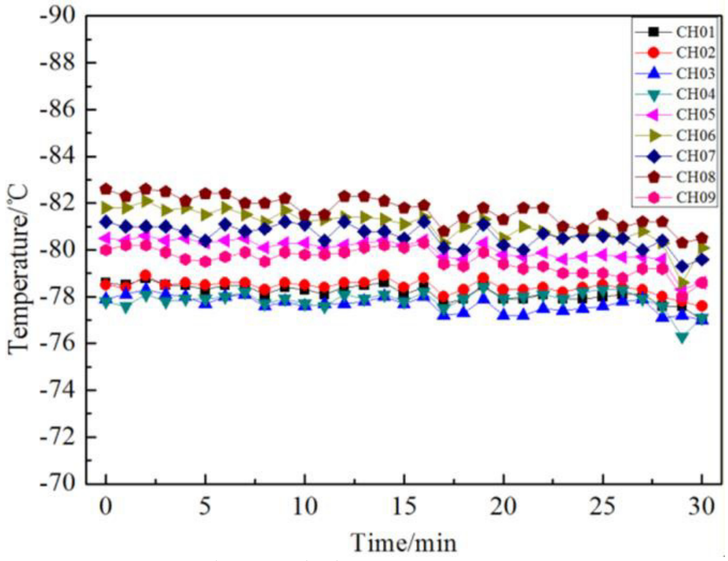

Fig. 6 A no-load test temperature curve

3. Effects of cryogenic treatment on roll

A 9Cr3Mo roll with the size of Φ260mm has been cryogenic treated in this developed system. The roll was quenched at 900 ℃ first and tempered after a process of cryogenic treated at -120 ℃. A test has been conducted by X-350A X-ray stress analyzer. The test results are shown in Fig. 7 and table 1.

Through the analysis of the test results, it can be concluded that: (a) the amount of residual austenite can be reduced after cryogenic treatment, shown in Fig. 7. (b) The depth of hardened layer has been thicker and the hardness of the roll has been improved. (c) The distribution of stress has been improved and the residual stress has been reduced, shown in table 1.

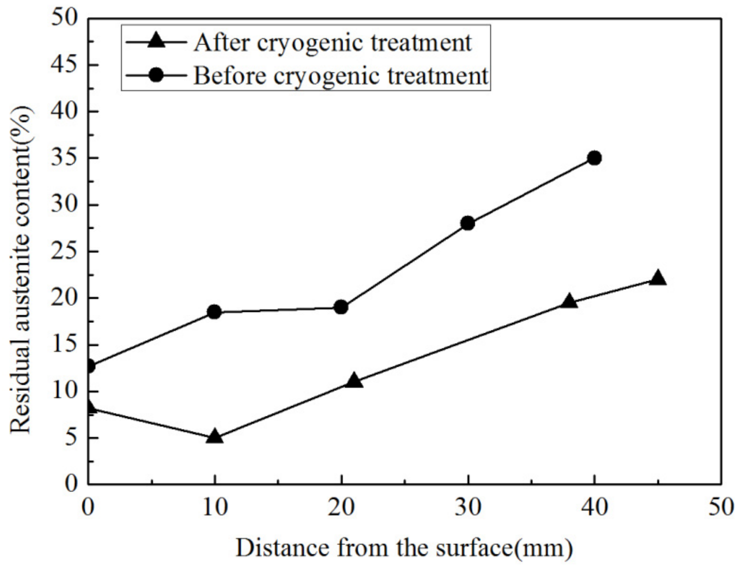

Fig. 7 the content of residua austeniter

Table 1 the residual stresses of roll before and after cryogenic treatment

	Hardness of the surface（HSD）	axial direction residual stresses (kgf/mm^2)	radial direction residual stresses (kgf/mm^2)	residual austenite（%）
After	97	-115	-100	8%
Before	95	-131	-117	15%

Cryogenic treatment is a supplementary process of conventional heat treatment to improve the microstructure and mechanical properties of metals. To cool down the rolls after quenching to below its Mf point further, most of the residual austenite changed into martensite, thus the hardness and dimensional stability improved.

4. Conclusions

A cryogenic treatment system for treating large rolls has been designed, built and tested. Liquid nitrogen has been employed to provide cooling capacities; and the temperature can be controlled from -180 ℃ to the room temperature with an accuracy of ±3 ℃ by the developed temperature controller.

A 9Cr3Mo roll with the size of Φ260 mm has been cryogenic treated in this developed system. The test results showed that most of the residual austenite would be changed into martensite after cryogenic treatment, which contributed to the improved hardness and dimensional stability.

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